RTB Workshop Report

Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

Marcelo Precoppe

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Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

INTRODUCTION

A training to strength the capacity of CIAT scientist on evaluating the energy performance of pneumatic dryers has been prepared and delivered. Appendix 1 describes the content, structure, and schedule of the planned activities.

TRAINING

The training aimed to build knowledge on: (1) fundamental principles of drying, (2) experimental techniques in drying, (3) data management and manipulation, (4) energy performance evaluation of dryers. However, the training had to be shortened because: (a) the participants were engaged on other activities and not readily available, (b) the dryer assembly was not completed, (c) the sensors have not been programmed and installed, (d) additional sensors needed to be acquired. Appendix 2 shows the content of the shortened training.

The training was anchored on the constructivist learning theory and therefore knowledge was built from the experience of the participants. Traditional classroom format, with lectures and slides-presentation, was not used. Instead, activities were hands-on, with problem-solving exercises, as shown in Figure 1. Appendix 3 and Appendix 4 contain the learning material handed to the participants.

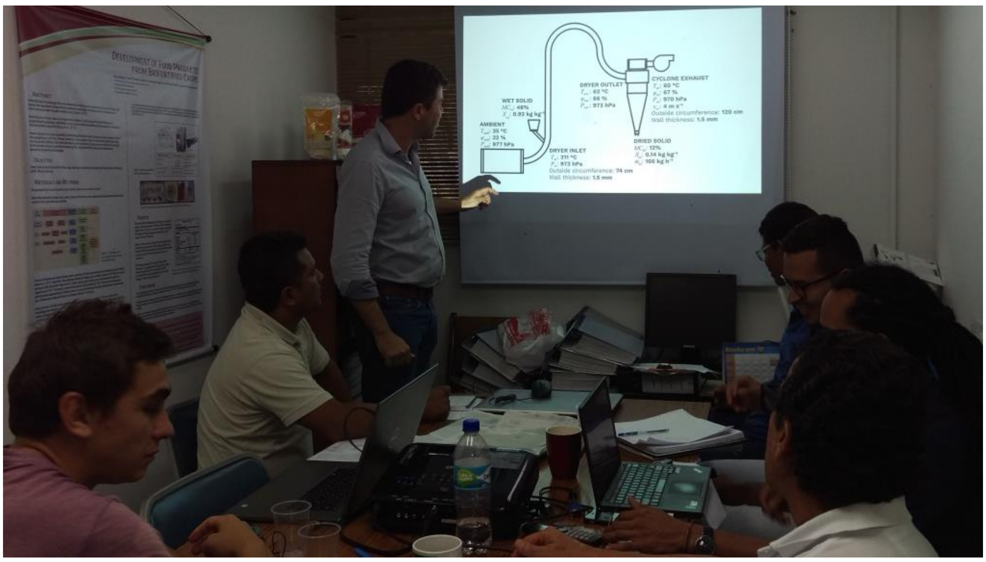

Figure 1 *Problem-solving exercise to strength CIAT engineers' skills on performance evaluation of pneumatic dryers*

At the end of the training an evaluation form was distributed (Appendix 5). The training scored 8.8 on a 9-point hedonic scale regarding overall satisfaction (Figure 2).

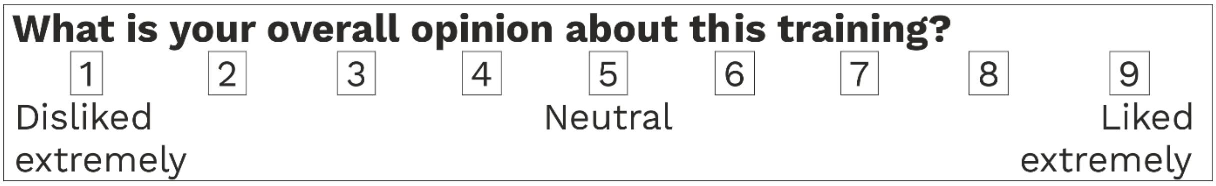

Figure 2 *Hedonic scale used to evaluate participants overall satisfaction*

ADDITIONAL ACTIVITIES

A measuring protocol for drying performance evaluation was developed (Appendix 6) as well as a guide for the acquisition of the additional needed sensors (Appendix 7). Furthermore, the already acquired measuring instruments (Figure 3) were programmed and installed at the dryer.

Figure 3 *Datalogger plus sensors programmed and installed at CIAT's pneumatic dryer*

Additional activities included troubleshooting the dryer and its heating unit, plus guiding CIAT scientists on how to calculate the dryer's optimum operating conditions regarding, wet solid feeding rate, drying temperature and air mass flow.

CONCLUSIONS

The equipment built at CIAT is the first dryer designed using the mathematical model on pneumatic drying of cassava. The dryer features an adjustable drying-duct length that allows determining its influence on the equipment energy performance. High-quality measuring devices were installed at the dryer and CIAT scientist learned how to use them. They have also learned how to perform energy performance experiments and to calculate energy performance indices. However, additional capacity building on data management and data manipulation might be needed, as it was not covered during the training.

RESEARCH PROGRAM ON Roots, Tubers and Bananas

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Appendix 1

Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

Facilitated by Dr Marcelo Precoppe
Crop Postharvest Technologist | Food and Markets Department | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Background

Industrial, large-scale pneumatic dryers, used for cassava processing, have been developed over a long period of time, and are nowadays highly efficient (Sriroth et al., 2000). In contrast, small-scale dryers, of a size suitable for village based processing, are still on early stage of development and presents low energy efficiency (Precoppe et al., 2017), the main reason being due to improper dimensioning of the equipment (Precoppe et al., 2016).

For several years, pneumatic dryers were dimensioned empirically, by building it at varied sizes and testing it, until the proper dimensions were achieved. Lately, with the aid of drying models, finding the proper dimensions became faster and easier (Kemp 1994). Pneumatic drying models have been already developed for several food products (Pelegrina and Crapiste 2001, Tanaka *et al.* 2008) and recently, Chapuis et al. (2016) developed a modeled for cassava starch. This model has revealed that the length of the drying-duct is the most important design parameter affecting equipment's energy performance (Chapuis et al., 2016).

In 2017, a small-scale dryer, designed and dimensioned based on the model developed by Chapuis et al. (2016), was built at the International Center for Tropical Agriculture (CIAT), Colombia. To evaluate the effect that the drying-duct length has on the energy performance of the equipment, the unit was assembled with a drying-duct of adjustable length. To strength the capacity of CIAT scientist on evaluating the energy performance of this dryer, a training has been organized.

Training structure

The training will be anchored on the constructivist learning theory (Piaget & Inhelder, 1969; Vygotsky & Cole, 1978) and therefore knowledge will be build base on the experience of the participants. Traditional classroom format, with lectures and slides-presentation, will not be used. During the training, participants will be active in the learning process. Most activities will be hands-on, with real measurements, problem-solving exercises, and concrete calculations.

Intended participants

Only the people directed involved and fully engaged on evaluating the dryer energy performance should participate of the training as this assures that the learning subjects have immediate relevance to their work. Participants must be able to be present on all activities of the training.

Training content

The training will be problem-centred and not content-oriented, as suggested by Knowles (1980) for adult education. In addition, the curriculum will depend on the prior knowledge of the participants. Nevertheless, to be able to evaluate the dryer, by the end of the training, participants will have built knowledge on fundamental principles of drying, experimental techniques in drying, data management and manipulation, plus energy performance evaluation of dryers, as shown in Table 1.

Table 1 *Knowledge needed to evaluate the energy performance of pneumatic dryers.*

Fundamental principles of drying	Experimental techniques in drying	Data management and manipulation	Energy performance evaluation of dryers
Thermodynamic properties of moist air	Experimental design	Data cleaning	Energy efficiency
Thermodynamic properties of moist solids	Data collection	Data transformation	Specific energy consumption
Heat and mass transfer	Sensors management	Data extraction	Specific energy utilization
	Statistical analysis	Data loading	Heat losses

In the section on fundamental principles of drying, knowledge will be built on psychrometry and psychrometric calculations, including psychrometric charts and Mollier diagrams. Calculations on moist air density, latent heat of vaporization and specific heat capacity will also be learned. Related to moist solids, knowledge will be built on moisture content, moisture sorption isotherms, water activity and drying kinetics.

The section on experimental techniques in drying will include the measurements at the dryer, such as airflow rate, temperature, relative humidity, product throughput and measurements to be carried out in a laboratory, like the moisture content of the solids.

In the data management and manipulation section, participant will learn how to clean, organize and prepare for calculations the data obtained from the sensors and from the laboratorial analysis. Focus will not be given to a software but it will be emphasized the need of use of a programming language that allows automatization via script writing.

Finally, in the section on energy performance evaluation of dryers, participants will learn how to calculate the parameters used to analyse the performance of the equipment.

Training schedule

Table 2 shows the proposed schedule, that includes one week of deskwork for preparing the training and three weeks at CIAT facilitating it. Exactly training timetable will be agreed with the participants to assure their uninterrupted presence on all activities.

Table 2 *Scheduled activities.*

Activities	August 2017				September 2017			
Training preparation (deskwork)	■	/	/				/	/
Training facilitation (CIAT, Colombia)		/	/	■	■	■	/	/

Budget

A total of 22 commissioning days at NRI rate (cost band H), travel expenditures, visa fee, subsistence costs, accommodation expenses and transport charges.

Expected results

At the end of the training CIAT scientists will be able to determine the energy performance of the pneumatic dryer at different drying-duct lengths.

References

Chapuis, A., Precoppe, M., Méot, J. M., Sriroth, K., & Tran, T. (2016). Pneumatic drying of cassava starch: Numerical analysis and guidelines for the design of efficient small-scale dryers. *Drying technology*, *35*, 393–408.

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Precoppe, M., Tran, T., Chapuis, A., Müller, J., & Abass, A. (2016). Improved energy performance of small-scale pneumatic dryers used for processing cassava in Africa. *Biosystems Engineering*, *151*, 510–519.

Sriroth, K., Piyachomkwan, K., Wanlapatit, S., & Oates, C. G. (2000). Cassava starch technology: The Thai experience. *Starch - Stärke*, *52*, 439–449.

Vygotsky, L. S., & Cole, M. (1978). *Mind in Society: Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Appendix 2

Training on energy performance evaluation of pneumatic dryers

Facilitated by Dr Marcelo Precoppe
Crop Postharvest Technologist | Food and Markets Department | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Background

Industrial, large-scale pneumatic dryers, used for cassava processing, have been developed over a long period of time, and are nowadays highly efficient (Sriroth et al., 2000). In contrast, small-scale dryers, of a size suitable for village based processing, are still on early stage of development and presents low energy efficiency (Precoppe et al., 2017), the main reason being due to improper dimensioning of the equipment (Precoppe et al., 2016).

For several years, pneumatic dryers were dimensioned empirically, by building it at varied sizes and testing it, until the proper dimensions were achieved. Lately, with the aid of drying models, finding the proper dimensions became faster and easier (Kemp 1994). Pneumatic drying models have been already developed for several food products (Pelegrina and Crapiste 2001, Tanaka *et al.* 2008) and recently, Chapuis et al. (2016) developed a modeled for cassava starch. This model has revealed that the length of the drying-duct is the most important design parameter affecting equipment's energy performance (Chapuis et al., 2016).

In 2017, a small-scale dryer, designed and dimensioned based on the model developed by Chapuis et al. (2016), was built at the International Center for Tropical Agriculture (CIAT), Colombia. To evaluate the effect that the drying-duct length has on the energy performance of the equipment, the unit was assembled with a drying-duct of adjustable length.

Training structure

In collaboration with the Natural Resources Institute, University of Greenwich, a training on energy performance evaluation of pneumatic dryers has been organized. The training will be anchored on the constructivist learning theory (Piaget & Inhelder, 1969; Vygotsky & Cole, 1978) and therefore knowledge will be built on the previous experiences of the participants. Traditional classroom format, with lectures and slides-presentation, will not be used. Learning activities will be hands-on, with real measurements, problem-solving exercises, and concrete calculations.

Intended participants

Those interest on learning how to evaluate the energy performance of pneumatic dryers. Participants must be able to attend all the training activities.

Training content

The training will be problem-centred and not content-oriented; therefore, the curriculum will depend on the prior knowledge of the participants. Nevertheless, Table 1 shows what participants will learn during the training. The training will be held in Spanish.

Table 1 *Learning objectives of the training on energy performance evaluation of pneumatic dryers.*

Energy performance evaluation of dryers	Experimental techniques in drying
▪ Energy efficiency ▪ Specific energy consumption ▪ Specific energy utilization ▪ Heat losses	▪ Experimental design ▪ Data collection ▪ Sensors management

Training timetable

Training will spam over a period of 8 days, from 6th to 15th of September 2017. Sections will be daily, two hours long, from 14:00 to 16:00. Table 2 show the training timetable.

Table 2 *Time table of the training sections on September 2017.*

	WED	THU	FRI		MON	TUE	WED	THU	FRI
	6	7	8		11	12	13	14	15
13				13					
14	**Training** Energy performance evaluation of dryers	**Training** Energy performance evaluation of dryers	**Training** Energy performance evaluation of dryers	14	**Training** Energy performance evaluation of dryers	**Training** Experimental techniques in drying	**Training** Experimental techniques in drying	**Training** Experimental techniques in drying	**Training** Experimental techniques in drying
15				15					
16				16					

Expected results

At the end of the training participant will be able to conduct data collection to determine the energy performance of the pneumatic dryer at different drying-duct lengths.

References

Chapuis, A., Precoppe, M., Méot, J. M., Sriroth, K., & Tran, T. (2016). Pneumatic drying of cassava starch: Numerical analysis and guidelines for the design of efficient small-scale dryers. *Drying technology*, *35*, 393–408.

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Appendix 3

Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

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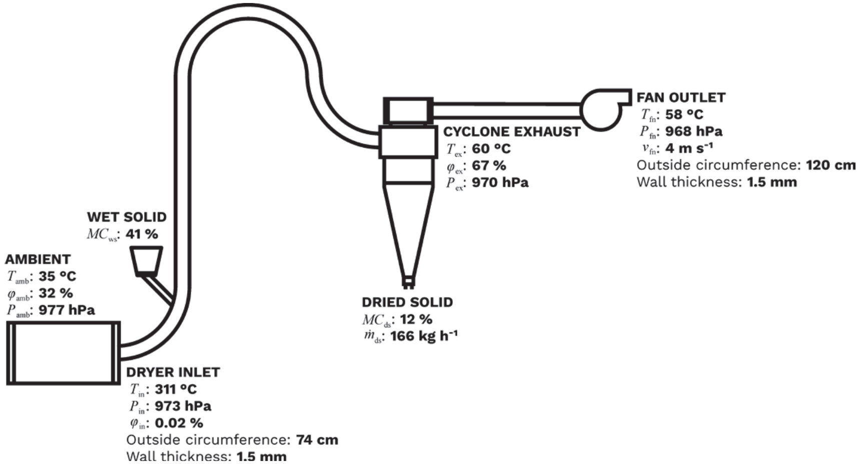
Exercise

Based on the measurements shown, made on a small-scale pneumatic dryer used to process cassava starch, calculate the following energy performance indices.



Performance indices	
Heat input rate ($\dot{Q}_{in}$)	______________ kW
Specific energy consumption (q_s)	______________ MJ kg_{water}^{-1}
Specific heat utilisation (q_U)	______________ MJ kg_{ds}^{-1}
Energy efficiency (η)	______________ %
Dryer inlet air velocity (v_{in})	______________ m s^{-1}

Nomenclature

Notation	
Q_{st}	heat of sorption (kJ kg⁻¹)
h	enthalpy (kJ kg⁻¹)
$\dot{m}$	mass flow rate (kg h⁻¹)
MC	moisture content on wet basis ($\%_{wb}$)
P	pressure (kPa)
$\dot{Q}$	heat rate (kJ h⁻¹)
q_E	specific electricity utilisation (MJ kg⁻¹)
q_s	specific energy consumption (MJ kg⁻¹)
q_U	specific heat utilisation (MJ kg⁻¹)
T	temperature (°C)
v	air velocity (m s⁻¹)
X	moisture content on dry basis (kg kg⁻¹)
Y	absolute humidity (kg kg⁻¹)
Greek letters	
η	energy efficiency (%)
φ	relative humidity (%)
λ	latent heat of vaporization (MJ kg⁻¹)
ρ	density (kg m⁻³)
Subscripts	
in	dryer inlet
amb	ambient
dm	dry matter
ds	dried solid
ex	cyclone exhaust
fn	fan outlet
in	input
out	dryer outlet
w	water
ws	wet solid

Absolute humidity (g_{water} $kg_{dry\ air}^{-1}$)

The absolute humidity (Y) can be calculated from measured values of temperature (T) relative humidity (φ) and pressure (P).

Air enthalpy (kJ $kg_{dry\ air}^{-1}$)

Enthalpy of the air (h) can be calculated from measured values of temperature (T) relative humidity (φ) and pressure (P).

Solid moisture content on a dry basis (kg_{water} kg_{dm}^{-1})

Solid moisture content on a dry basis (X) is measured at the lab, most commonly using the oven method.

Solid mass flow rate on a dry basis (kg_{dm} h^{-1})

The solid mass flow rate on a dry basis ($\dot{m}_{dm}$) is calculated from dried solid output rate ($\dot{m}_{ds}$) and the dried solid moisture content (MC_{ds} or X_{ds}).

Air density (kg m⁻³)

Density of the air (ρ) is calculated from measured values of temperature (T) relative humidity (φ) and pressure (P) Calculated from air temperature relative humidity and pressure.

Appendix 3

Air mass flow rate on dry basis ($kg_{dry\ air}\ h^{-1}$)
Air mass flow rate ($\dot{m}_{air}$) measured air velocity and cross-sectional area plus the calculated is calculated air density (ρ).

Heat input rate to the dryer (kW or MJ h^{-1})
Heat input rate ($\dot{Q}_{in}$) is the energy rate added to the ambient air and is calculated as shown:

$$\dot{Q}_{in} = \dot{m}_{air}\left(h_{in} - h_{amb}\right)$$

Where $\dot{m}_{air}$ is the air mass flow rate, h_{in} is the enthalpy of the air at the dryer inlet and h_{amb} is the enthalpy of the ambient air.

Water evaporation rate ($kg_{water}\ h^{-1}$)
The water evaporation rate ($\dot{m}_w$) is calculated based on the solid mass flow rate on a dry basis ($\dot{m}_{dm}$) and the difference between the wet solid moisture content on a dry basis (X_{ws}) and the dried solid moisture content on a dry basis (X_{ds}):

$$\dot{m}_w = \dot{m}_{dm}\left(X_{ws} - X_{ds}\right)$$

Specific energy consumption (MJ kg_{water}^{-1})
Specific energy consumption (q_s) is the ratio between the heat input rate to the dryer ($\dot{Q}_{in}$) and the water evaporation rate ($\dot{m}_w$):

$$q_s = \frac{\dot{Q}_{in}}{\dot{m}_w}$$

Specific heat utilisation (MJ kg_{ds}^{-1})
Specific heat utilisation (q_U) provides information on the amount of thermal energy needed to obtain 1 kg of dry solid. It is calculated as the ratio between the heat input to the dryer ($\dot{Q}_{in}$) and the dry solid output rate ($\dot{m}_{ds}$):

$$q_u = \frac{\dot{Q}_{in}}{\dot{m}_{ds}}$$

Heat rate used for moisture evaporation (MJ h^{-1})
Heat rate used for moisture evaporation ($\dot{Q}_w$) is obtained by multiplying the water evaporation rate ($\dot{m}_w$) with the latent heat of water vaporisation (λ):

$$\dot{Q}_w = \dot{m}_w \cdot \lambda$$

However, when data is available, the heat of sorption (Q_{st}) of the drying solid should be used instead because Q_{st} accounts for the energy required to overcome capillary forces.

$$\dot{Q}_w = \dot{m}_w \cdot Q_{st}$$

Energy efficiency (%)
Energy efficiency (η) is the ratio between the heat rate used for moisture evaporation ($\dot{Q}_w$) and the heat rate supplied to the dryer ($\dot{Q}_{in}$):

$$\eta = \frac{\dot{Q}_w}{\dot{Q}_{in}}$$

Exercise solution

Cyclone exhaust absolute humidity ($g_{water}\ kg_{dry\ air}^{-1}$)	99.14
Fan outlet volume flow ($m^3\ h^{-1}$)	1624.3
Fan outlet relative humidity (%)	73.54
Fan outlet absolute humidity ($g_{water}\ kg_{dry\ air}^{-1}$)	99.38
Fan outlet air density dry basis ($kg_{dry\ air}\ m^{-3}$)	0.88
Dryer air mass flow rate on a dry basis ($kg_{dry\ air}\ h^{-1}$)	1426.5
Ambient air absolute humidity on a dry basis ($g_{water}\ kg_{dry\ air}^{-1}$)	11.65
Ambient air enthalpy on a dry basis (kJ $kg_{dry\ air}^{-1}$)	64.75
Dryer inlet absolute humidity on a dry basis ($g_{water}\ kg_{dry\ air}^{-1}$)	13.03
Dryer inlet enthalpy on a dry basis (kJ $kg_{dry\ air}^{-1}$)	371.49
Heat input to the dryer (MJ h^{1})	437.56
Heat input to the dryer (kW)	121.54
Wet solid moisture content on dry basis (kg kg^{-1})	0.69
Dried solid moisture content on dry basis (kg kg^{-1})	0.14
Dried matter mass flow on a dry basis ($kg_{dry\ matter}\ h^{-1}$)	146.08
Wet solid mass flow on a wet basis ($kg_{wet\ solid}\ h^{-1}$)	247.59
Water evaporation rate (kg h^{-1})	81.59
Specific energy consumption (MJ kg_{water}^{-1})	5.36
Specific heat utilisation (MJ $kg_{dried\ solid}^{-1}$)	2.64
Wet solid heat of sorption (MJ kg^{-1})	2.48
Dried solid of sorption (MJ kg^{-1})	2.52
Average heat of sorption (MJ kg^{-1})	2.50
Heat rate used for moisture evaporation (MJ h^{-1})	203.86
Dryer energy efficiency (%)	46.59
Dryer inlet air density ondry basis ($kg_{dry\ air}\ m^{-3}$)	0.57
Dryer inlet volume flow ($m^3\ h^{-1}$)	2509.8
Dryer inlet air velocity (m s^{-1})	16.41

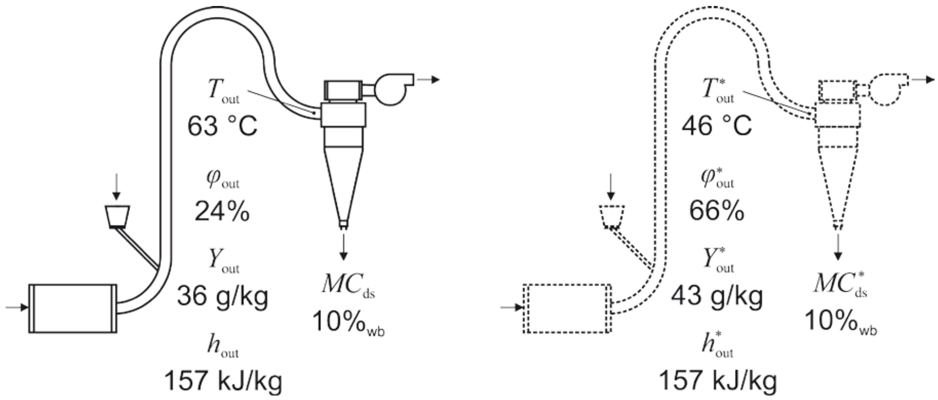
Appendix 4

Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

Facilitated by Dr Marcelo Precoppe
Crop Postharvest Technologist | Food and Markets Department | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Lowest air temperature (°C) and highest relative humidity (%) at the outlet

Lowest allowable air temperature at the dryer outlet (T^*_{out}) and the highest allowable relative humidity at the dryer outlet (φ^*_{out}) is calculated considering the air enthalpy at the dryer outlet (h_{out}), and the equilibrium moisture content (MC^*_{ds}) of the dry solid, determined by sorption isotherms. The value of h_{out} should be calculated from T_{out} and φ_{out} measured at the dryer. The values for T^*_{out} and φ^*_{out} is then calculated, with h^*_{out} constrained to be equal to h_{out} and MC^*_{ds} equal to the target moisture content (e.g. 10%$_{wb}$).



Minimum air mass flow rate (kg h⁻¹)

Minimum air mass flow rate $(\dot{m}^*_{air})$ is determined considering the dryer's aerodynamic and heat demand. Air velocity in the drying duct should remained higher than the terminal velocity of the largest particle and enough thermal energy to dry the solid should be delivered.

First, both the lowest allowable air temperature at the dryer outlet (T^*_{out}) and the highest allowable relative humidity at the dryer outlet (φ^*_{out}) needs to be calculated, and then, based on these calculations, the highest possible absolute humidity at the outlet (Y^*_{out}) is determined and used to calculate $\dot{m}^*_{air}$:

$$\dot{m}^*_{air} = \frac{\dot{m}_w}{Y^*_{out} - Y_{amb}}$$

Appendix 5

What is your overall opinion about this training?

1	2	3	4	5	6	7	8	9
Disliked extremely				Neutral				Liked extremely

Write whatever you want:

Appendix 6

Capacity building on energy performance evaluation of a pneumatic dryer with adjustable drying-duct length

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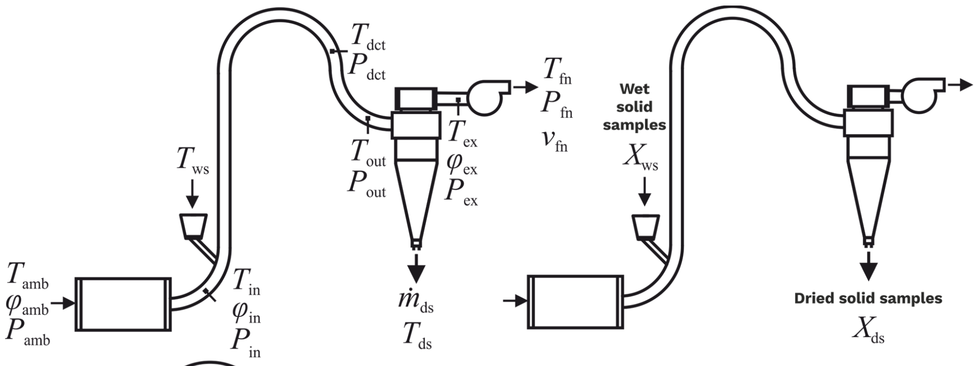
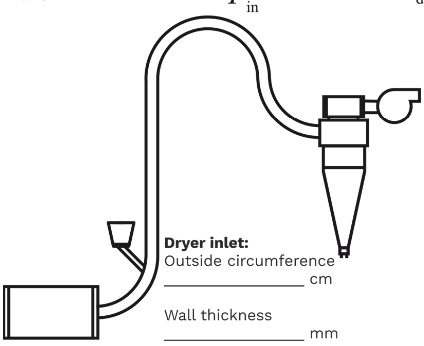
Data collection





Cyclone air outlet:
Outside circumference
________________ cm

Wall thickness
________________ mm

Dryer inlet:
Outside circumference
________________ cm

Wall thickness
________________ mm

Bucket number	Start time (hh:mm)	Finish time (hh:mm)

Notation

$\dot{m}$	mass flow rate (kg h^{-1})
P	pressure (kPa)
T	temperature (°C)
v	air velocity (m s^{-1})
X	moisture content on dry basis (kg kg^{-1})

Greek letters

φ	relative humidity (%)

Subscripts

in	dryer inlet
amb	ambient
ds	dried solid
dct	drying duct
ex	cyclone exhaust
fn	blower outlet
in	input
out	dryer outlet
ws	wet solid

Appendix 7

Sensors needed to evaluate the energy performance evaluation of pneumatic dryers

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Crop Postharvest Technologist | Food and Markets Department | Natural Resources Institute | Faculty of Engineering and Science | University of Greenwich

Introduction

This document aims to describe the sensors needed for the energy performance evaluation of pneumatic dryers. Figure 1 shows the measurements required.

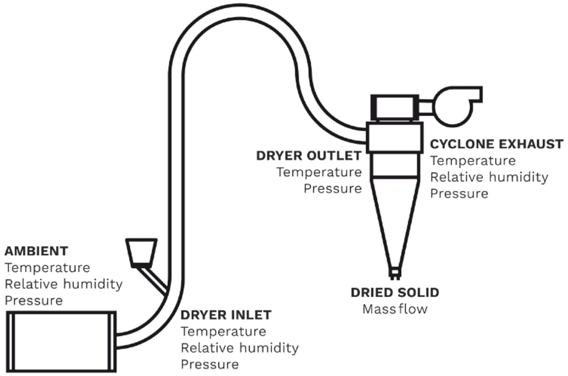

Figure 1 *Measurements needed for the energy performance evaluation of pneumatic dryers.*

Ambient

Ambient air temperature and relative humidity will be measured using a thermometer-hygrometer (FHAD 46-C7; Ahlborn, Eichenfeldstraße, Germany). This sensor works with a temperature measuring range from -20 °C to +80 °C and relative humidity from 5 % to 98 %. Ambient pressure will be measure by the data logger (Almemo 710; Ahlborn) integrated sensors that works with a pressure range from 700 hPa to 1100 hPa.

Dryer Inlet

Temperature and relative humidity at the dryer inlet will be measured with a temperature resistant thermometer-hygrometer (HC2-IEXXX-M; Rotronic, Bassersdorf, Switzerland). This is a screw-in probe temperature measuring range from -50 °C to 200 °C) and relative humidity from 0 % to 100 %. To connect to the data logger an Almeno D6 cable is needed. Pressure at this location will be measured with a temperature resistant pressure transducer.

Dryer outlet

Temperature of the air at this location will be measured using a thermocouple (Pt100; Ahlborn). This sensor works on a temperature range from –50 °C to +200. Pressure will be measured with a digital pressure sensor (FDAD35M01A; Ahlborn). This sensor measure pressure from 1000 hPa to 1×10^{6} hPa and operates on a temperature range from e -40 to +120 °C.

Dried solid

Mass flow of the dried solid will be measured using a load cell connected to the data logger.

Cyclone exhaust

Temperature and relative humidity of the air at the cyclone exhaust will be measured with a thermometer-hygrometer (HC2A-S; Rotronic) that measured temperature from -50 °C to 100 °C and relative humidity from 0 % to 100 %. This probe is connected to the data logger with a Almeno D6 cable. Pressure will be measured with another FDAD35M01A (Ahlborn).

Data recording

All sensors will be connected to a data logger (Almemo 710; Ahlborn) and data will be saved at 10 second intervals.

Additional sensors required

Figure 2 shows the measurements where acquisition of additional sensors is needed. Needed.

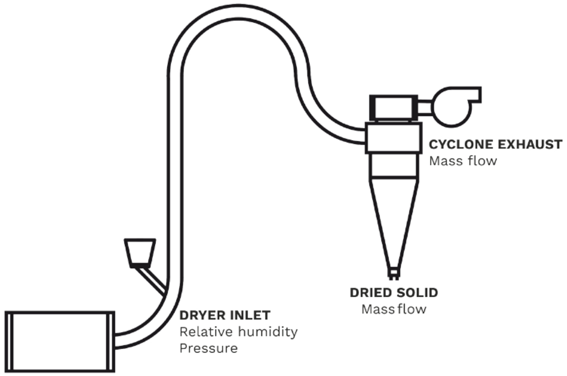

Figure 2 *Measurements that require the acquisition of additional sensors.*

Air mass flow rate can be obtained by diverse ways as shown on Figure 3. It can be calculated from measuring air velocity at the drying inlet as shown on Figure 3a. For this measurement, a temperature resistant pitot tube will be required.

Alternative air mass flow rate can be calculated from measuring air velocity at the cyclone exhaust as shown on Figure 3b. For this measurement, a temperature resistant vane anemometer would be needed.

Another possibility would be to measure air mass flow rate direct possibly at the cyclone exhaust as shown on Figure 3c. This measure is done with a mass flow transmitter (e.g. THERMATEL TA2; Magnetrol, Aurora, Illinois, USA).

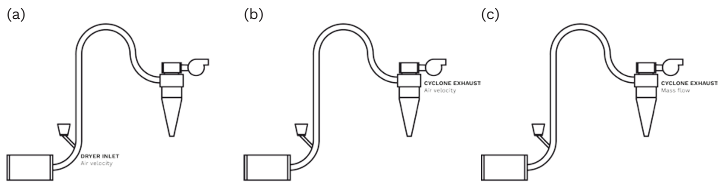

Figure 2 *Possible measurements for determining the dryer air mass flow rate.*